AC 2009-358: A MULTIDISCIPLINARY COLLABORATIVE MODEL PROJECT EMPHASIZING ELEMENTS FROM ELECTRICAL ENGINEERING, MECHANICAL ENGINEERING, AND SCIENCE MAJORS

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A Multidisciplinary Collaborative Model Project Emphasizing Elements from Electrical Engineering, Mechanical Engineering, and Science Majors

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Abstract:
The multidisciplinary activities within the MURI (Multidisciplinary Undergraduate Research Initiative) program conducted at IUPUI campus require departmental and school collaboration from across the campus. A research project model is described here to emphasize research elements from physics, electrical and computer engineering, and mechanical engineering that addresses issues related to thermal sciences, physics, solid state devices, CAD, and energy conversion—all combined in one project. The project proposes a new methodology to optimize compound semiconductor thermal and electrical properties optimized for high speed operation and properly interfaced across the composite device layers. The mathematical model incorporating the differential equations with boundary conditions across various interfaces was developed. The paper details the research plan, methodology, and the findings of the project. This model was chosen to build on pre-requisite materials covered in ECE, ME, and Physics curricula such as thermal sciences, semiconductor devices, solid state physics, electromagnetics, CAD, and mathematical simulation tools. The results obtained during one semester have proved the hypothesis of the project leading to optimum performance of metallic semiconductor interface with high speed exciton carrier conversion efficiency within the compound

semiconductor. Some of the variables considered in this model include complex electron tunneling, exciton recombination at tunneling interfaces, and thermal communication in semiconductor devices. The learning objectives within the given research will be reported.

I. Introduction

The importance of multidisciplinary undergraduate research activities have been emphasized recently by many campuses across the United States. The multidisciplinary undergraduate research initiative (MURI)[1] at the Indiana University Purdue University Indianapolis (IUPUI) was established in 2004, to enhance undergraduate students across the campus to pursue research projects to serve the community. Research projects are proposed every semester including summer sessions, and the selected projects are those that pass the screening and reviewing process. Within the MURI program at IUPUI, the integration of knowledge from various fields can be put together in a research project to accomplish enhanced performance devices and systems resulting in smart functions, better reliability, and high efficiency.

In the popular media, there is a growing interest in alternative energy sources and renewable energy technologies. This same interest is reflected in the student body, and so, the primary investigators for this particular project saw this as an excellent opportunity to create a research project that would be both academically useful, intellectually interesting, and have popular interest based on these technologies.

II. MURI Project Process and Assembled Team

The process of MURI funded projects starts by accepting proposals from IUPUI campuses that require different discipline backgrounds. After the reviewing process, the MURI screening committee selects the best 8 to 10 proposals per semester for funding. The selection criterion is based on the multidisciplinary aspects of the research team, the pre-requisite materials required by students, the clarity and values of the research project. This paper details the integration of knowledge from engineering and science backgrounds in order to complete the research work for the development of the final mathematical model.

The general area of the proposed project is renewable energy—specifically, a new photovoltaic cell that is designed from compound semiconductor materials built on a metallic substrate. The selection of the materials and research programs determines the proper materials, dimensions, and manufacturability of the new device. As a multidisciplinary project, the following background is needed for the project.

A. Student Backgrounds
   1. Electrical Engineering: solid state devices
   2. Computer Engineering: CAD tools and IC processes
   3. Mechanical Engineering: thermal sciences
   4. Sciences: solid state physics

B. Faculty Supervisor Backgrounds
   1. Electrical and Computer
   2. Mechanical Engineering
   3. Science: Physics or Chemistry

Given the background requirements for the students, one student who was pursuing a dual major degree (BS in Physics and BS in Electrical Engineering) was chosen. This student fulfilled both the solid state physics and thermal science requirements, because he took a ME thermodynamics class as part of his elective course work. Another student from electrical and computer engineering was chosen based on his background in CAD tools, computer simulation, solid state devices, electronics, and electromagnetics.

III. The Project

The proposed photovoltaic cell is based on compound semiconductor materials that were chosen based on a high Fermi potential difference that optimizes high thermal carrier generation and assists collection of the generated carriers via a tunneling oxide layer. This is a novel energy technology different from the current traditional technologies[2,3] because it allows for direct isothermal to electrical energy conversion. From a teaching standpoint, it was ideal because the problems it proposed required a multidisciplinary approach, the simulation and modeling of the operation and design of the device were approachable and iterative, and the results were applicable and interesting to the student body in general.

The project was a one semester, independent research project with the intended outcome being a mathematical model and computer simulation of the device's operation, and a recommendation for materials or material properties to be used for the optimization of the device based on the model and simulation. Aside from the model and simulation, the expected learning outcomes of the project included a deeper understanding of solid state physics and devices, device fabrication, design trade-offs and iterative design processes, and device simulation and modeling.

IV. Students' Activities

First, the research was segregated into four distinct sections: background research, fundamental operation modeling, functional device modeling, and optimization. To allow and facilitate the students' understanding and acclimation to academic research, it was decided to have the students participate in the planning and implementation of the research at each step. Initial estimations of the timeline for the semester were drawn up with these four sections in mind, and the students were made aware of the initial expected deadlines.

For the first step, background research, the students participated in several lectures and mentoring sessions with the primary investigators and other faculty with knowledge in related fields. Between the sessions, each student was assigned to perform further individual research on topics they showed interest in, had problems with, or would be responsible for later in the project. Additionally, they were each expected to bring questions and concerns up at the next meeting from their individual research. The group also determined it would be useful to have a central repository of parameter variables, valid ranges, and reference materials. These were assembled and one student was put in charge of maintaining these throughout the project. While it was not implemented during this semester, the authors would recommend that the students be required to provide at least one study session to their fellow students during this section of the research. It would be helpful to bring all students to the same level of knowledge of all parts of the research, would provide useful experience dealing with colleagues with differing abilities and knowledge, and would allow each student to codify their own learning by expressing it.

Next, the group, the faculty advisors and students, determined the primary fundamental concepts necessary for the modeling of the operation of the device. After the individual concepts were determined, the students were asked to propose and justify an appropriate order and segregation to address the individual problems, and an appropriate timeline for each problem. For our research project, the primary concerns were the electron probability distribution across high band-gap systems, the generation rate and associated generation current, and the heat transfer. At each step, the students were allowed to assign workload as necessary and appropriate for the best results, with an emphasis on group work and cross-disciplinary cooperation. Specifically, the group decided to allow the student who was most familiar with the specific problem to work as a make-shift team leader and delegate responsibilities as needed. After each portion of the research was completed, the students were asked to reassess their progress, and if any new concerns were raised from the recently completed work.

During this stage, it was the students' primary responsibility to generate mathematical models for the device's operation, under the guidance of the faculty. In most cases, the students were directed by the faculty toward the general concepts and theories that would be useful to model the device, but the students were ultimately responsible for researching and implementing the theories into cohesive models. The faculty had done some early work predicting what the expected materials, structure, and operation of the device would be, and it was the student's responsibility to provide more mathematically concrete models and optimization from the initial assumptions and expectations. For example, for the generation current model, the faculty advised the students to appropriate texts and references, but the students were responsible to research, identify, propose, and implement the appropriate theories and models. Throughout this stage of the research, the faculty and students met one to two times per week to discuss the student's progress, get feedback from the faculty, and allow the faculty to direct the student's work on a regular basis.

Third, the group addressed the functional device modeling by using the individual primary functional concept models to form as complex as necessary a model for the operation of the device in total. Similarly to the previous step, the students were asked to propose and justify an approach to integrate the previous concept models into one model that would provide a reasonable model for the entire device's operation. They were also asked to brainstorm any potential problems that might come up during the overall device model that would not have been an issue during the previous concept modeling. For our research, the individual concept models were modeled using Matlab. The final model was an amalgamation of the individual models, but took into account some specific assumptions and requirements made at each step of the initial models that would have affected the other models.

Lastly, using the completed device model, the group was asked to optimize the output of the device. The optimization was directed by the primary investigators for specific outcomes, but the students were asked to determine the appropriate variables or parameters to iteratively examine over the ranges determined during the initial background research to attain the required outcomes.

V. Results & Discussions

The assembled team was able to develop the solid state mathematical model and implement it in Matlab. Two representative plots from the simulation are shown—figure 1 shows the output current density versus temperature and figure 2 shows output current density versus an applied voltage. The computer simulation developed in this research project met the objectives of the project in two aspects: power conversion and power cooling. The first is related to the solar and thermal energy converted to electrical energy, while the second refers to the rate of flow of the power energy out of the device citing another important aspect for low power electronics applications. The project has received a grant award to fabricate the device with the specifications determined from the simulation results.

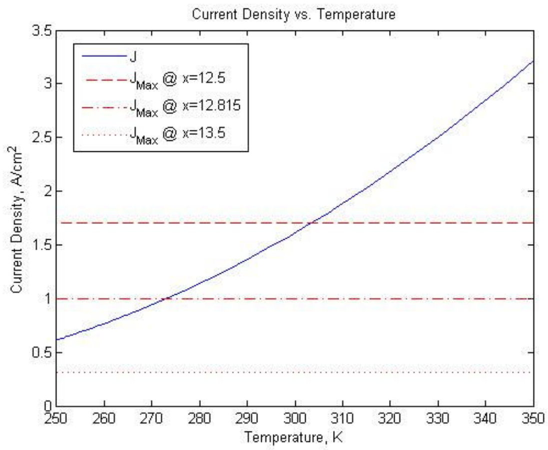

Figure 1 – Current Density versus Temperature

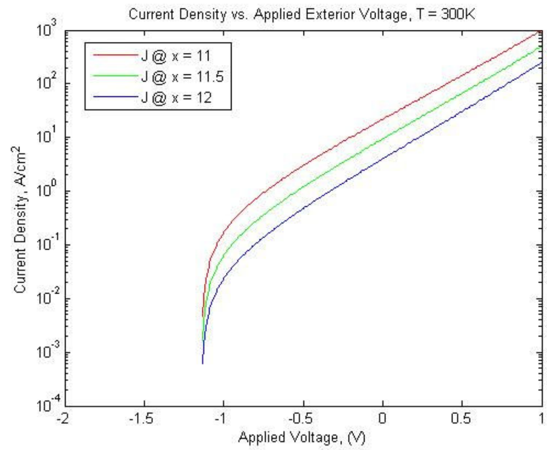

Figure 2 – Current Density versus Applied Voltage

The students' learning outcomes included practical experience and appreciation for iterative research methodology, a further understanding for the thought process behind research and researchers' approaches to the addressed problems, further experience and competence with Matlab and modeling software, and experience on how to conduct background research on new or previously unreported research. Additionally, because of the received grant, the students will be able to further continue their learning while continuing the project through device fabrication and testing.

VI. Acknowledgement

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VII. References

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